

Showers, Showers Everywhere

Until the Milagro experiment, gamma-ray astronomers had great difficulty detecting sources of gamma rays with energies as high as 10 to 100 TeV.

To detect a source of gamma rays in that energy range, one must detect at least 10 to 20 such gamma rays per day coming from a particular direction.

That's an impossible task for satellite-borne detectors. Their area is so small that the number of very high-energy gamma rays intercepting the detector's small area per year goes down to almost zero.

The ground-based gamma-ray telescopes known as atmospheric Cherenkov telescopes are much larger, but they cannot detect gamma rays directly because gamma rays never reach the ground. Instead, gamma rays produce a shower of secondary particles when they enter Earth's atmosphere (see figure below), and the atmospheric Cherenkov telescopes pick up the (Cherenkov) light radiated in the wake of those secondary particles.

Those telescopes have been very successful and were the first to discover a cosmic source of TeV gamma rays (the Crab Nebula, shown in the opening illustration). However, their narrow field of view, combined with the requirement for moonless, cloudless nights, restricts their viewing to a discrete number of directions and a limited viewing time (50 hours per year) in each direction. They therefore have difficulty detecting sources that emit gamma rays above 10 TeV or that are spread over a wide area in the celestial sky.

These limitations on field of view and observation time can be overcome by a ground-based array of particle detectors spread over a large area. This large-area array can operate around the clock and simultaneously view the entire overhead sky. However, it will detect only the shower particles that survive to ground level, and of those, only the small fraction, typically less than 1 percent, that intercept the sparsely distributed detectors. The rest fall, you might say, between the cracks. Large-area arrays are therefore sensitive to the showers from gamma rays that are 100 TeV and above because those showers cover the largest areas and generate the largest numbers of particles: millions of particles and more.

Unfortunately, the number of 100-TeV gamma rays entering Earth's atmosphere is so low that the enormous Cygnus array at Los Alamos and the Chicago Air Shower Array, covering over 200,000 square meters in Dugway, Utah, failed to detect a significant number of 100-TeV showers coming from any particular direction. Thus, no sources were found.

The Los Alamos team concluded that a successful ground-based array would have to be sensitive to showers from much lower-energy gamma rays—down to 0.1 TeV. At that energy, the showers are millions of times more numerous, but each shower contains only thousands as opposed to millions of particles, and many particles would be absorbed before reaching the ground. The array would therefore have to detect almost all the particles that reach the ground, which meant creating an array with end-to-end detectors. That approach would be way too expensive.